

## **Thermal Environment in Main Room Models of Contemporary Houses in Hokkaido, Japan**

### **Speakers:**

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**Abstract:** *This study aims to clarify how the room form and other factors have effects on indoor thermal environment and find out the thermal environment characteristics of models of main rooms such as a living room, in contemporary houses in Hokkaido, a cold climate area in Japan. We extracted eight basic form prototypes of modern houses in Hokkaido by their spatial dimension and the way of responding to the outside. In addition, we analyzed alternates that were changed from prototypes respectively and combinatorially in terms of building performance and living style. A PASSWORK design tool was used in this study to calculate the air conditioning load of each model. The present study has demonstrated the thermal environment characteristics of main room models of contemporary houses in Hokkaido and suggested the possibility to make an intimate relationship between indoor and outdoor spaces by using large windows in houses in cold climate areas.*

### ***Cold Climate Housing, Form, Heat Load, Indoor Thermal Environment, Parametric Study***

#### **1. Introduction**

The realization of comfortable house environment corresponding to the outdoor environment is a universal theme in designing houses and there is a lot of originality to achieve thermal comfort in each region.

This study focuses on how houses should be designed to adapt themselves to Hokkaido, the northern part of Japan and the winter temperature goes down to subzero. In designing houses in Hokkaido, measures against the cold weather are significant. Therefore, the principal objective for the development of the building technology in this region is “how to spend in winter comfortably” and an adiabatic construction method and heating technique have been studied and



**Image1. Houses in Hokkaido**

1-1 photo by Yoshiroshi Tsukada of Asahi Shinbun  
1-2 photo by Ping Hui

developed. The indoor environment comfort in winter greatly improved with these developments. After the establishment of “Act on Promotion of Construction, etc. of Housings with Cold Weather Protection in Hokkaido” in 1953, Hokkaido Housing Public Corporation played a key role and supplied concrete block construction houses as fireproof houses with protection against the cold. These houses with characteristics such as “Center-living room” and “Small windows” were typical in several decades. Various trials and errors to “open windows to solid walls” have been performed to adopt light and scenery without conveying cold from outside to inside. Recently, the housing has come to be designed more open: it has large windows to enable it to take light and have scenery aiming to suit its climate through the year as well as winter. Such changes in designing houses indicate that the various balances of space and environment has been considered in response to this local climate.

In addition, various room compositions are derived from “Center-living room” and many examples of contemporary houses whose plan is based on the living room were observed: a dining room and a living room adjoin, and a bedroom and a living room adjoin the upper part of the colonnade of a living room. Therefore, focusing on such continuous space connected with a living room would clarify how designers balance space and environment in Hokkaido. What is concerned here is indoor thermal environment affected by spatial dimension, composition of rooms, insulation performance and the residents’ living style. This study aims to clarify how the room shape and other factors have an effect on indoor thermal environment and to find out the thermal environment characteristics of models of main rooms, such as a living room and a dining room, in contemporary houses in cold climate areas.

## 2. Basic Shape Prototypes of Main Rooms

Eight basic shape prototypes of main rooms in Sapporo were extracted by considering the dimension and “room envelope composition”: the room envelope composition means ceilings and walls are exterior or interior.

This analysis is based on 96 contemporary houses in the Japanese architecture journals, *Shinkenchiku* and *Jutakutokushu* published during 32 years from 1980. The dimension of the main space was examined from the floor area and the height. The average of the floor area was 48.4 square meters and many of the houses were smaller than the average (Fig. 1). Houses with more than two stories was 72 of 96 houses and tended to open toward the perpendicular direction (Fig. 1). In Fig.1 and hereafter, **L** means larger than the average, **S** means smaller than the average, **s** means one story and **h** means two or three stories.

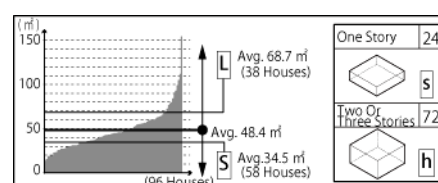


Figure 1. Covered Area and Elevation

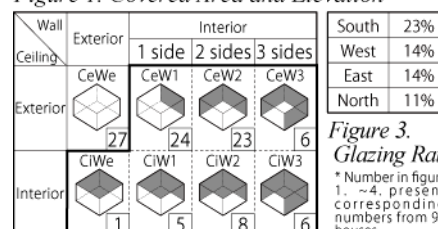


Figure 2. Room Envelope Composition

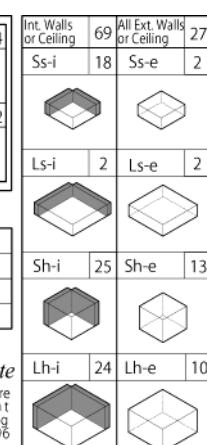


Figure 3. Glazing Rate

Figure 4. Shape Prototype

In addition we considered the dimension together with the room envelope composition (Fig. 2). Hereafter, **e** and **ext.** mean “both walls and ceilings are exterior” and **i** and **int.** mean “more than one part is interior of walls or ceilings”. In Fig. 2, **Ce** means “ceilings and floors are exterior” and **Ci** means “ceilings and floors are interior”. **We** means “walls are exterior”, **Wi** means “walls are interior” and **W1 or 2 or 3** means “one (or two or three) of the walls is (are) interior”. **Ce** was numerous. In contrast, **Wi** was numerous and mostly had an adjacent room in the north side. **Sh**, small area and high elevation, and **Lh**, large area and high elevation, were numerous and **Ls**, large area and short elevation, was not numerous. This shows the tendency to expand to the perpendicular direction, regardless of the area size.

When we focus on the combination of walls and ceilings in terms of exterior or interior, walls and ceilings that are both exterior were the most numerous and there are the examples that the main space occupies most of the floors. In the type of whose walls and ceilings are interior partition, two sides of the five sides were often interior. In addition, floors and walls dividing the main space in small parts was frequently observed. This shows that continuous space is divided into small parts by partitions such as walls and floors. When we examined “glazing rate” meaning windows to wall ratio in every direction, south glazing rate was highest and north one was lowest (Fig. 3). On the basis of such tendency of the dimension and the room envelope composition, main rooms are classified into eight basic shape prototypes (Fig. 4). Most of the patterns have more than one interior part, **i** was most numerous, and **Sh-i** and **Lh-i** were numerous. On the other hand, in the pattern of **e**, whose walls and ceilings are both exterior, **Sh-e** and **Lh-e** were also numerous and this shows the tendency to expand to the perpendicular direction.

### 3. Heat Load of Main Room Models

Changing shape influences heat load as shown in this chapter. The calculation of air conditioning load of each shape prototype at the baseline setting identifies the relationship between the amount of the air conditioning load and shape. To calculate, a PASSWORK design tool named “Solar Designer” was used in this study. Fig. 5 shows the baseline of the setting like climate, months and hours for air-conditioning, months and hours for natural ventilation and building performance. By analyzing annual air-conditioning heat load calculated according to the baseline, the thermal environment characteristic of basic shape prototypes of main room was examined (Fig. 6). When we focus on the room envelope composition, as for the difference of the air-conditioning load, the air-conditioning load of **i** was approximately 20% smaller than that of **e** in any pattern. In addition, when we focus on the dimension, the heat load of **Lh** was the highest, and that of **Ss** was the lowest.

For these, the airspace of **Ls** and **Sh** were almost the same and the heat load of them were almost the same. In all models, the proportion of the cooling load to the whole annual load was much smaller, and the heating load was high especially in a larger airspace. This shows the importance of measures against heating load.

Changing building performance and living style from baseline respectively, influence on the air conditioning load of each shape pattern was examined (Fig. 7). Building performance includes increasing and decreasing insulation performance, additional floor heat storage, and increasing and decreasing glazing rate. Living style includes increasing and decreasing the number of people, an additional nighttime shutter and additional summer green walls. Insulation performance is subject to the present insulation standard "Next Generation Energy-saving standard" revised in 1999.

When we focus on the building performance, as for **×2** and **V-window**, the heat load decreased more greatly than that of the baseline in all the shapes: **×2** means double thickness of insulation obeying the Next Generation Energy-saving Standard and **V-window** means vacuum insulated glass windows. As for **×2**, the heat load greatly decreased in the shapes of **Ss-e**, **Ss-i** and **Ls-e**. As for **V-window**, the heat load greatly decreased in the shapes of **Ss-i** and **Sh-i**. In addition, the heat load decreased in **Glazing -** of all directions especially in the north. Indecreasing the glazing rate of the north in the shapes of **Ss-i** and **Sh-i**, the heat load decreased substantially. In **Mass Floor**, the influence on increase and decrease of the heat load varied according to the shape and the load increased especially in the shape of **Ls**. Against such a technological advance of building performance, the load increased in **Old Standard** with the thickness of insulation obeying "New Energy-saving Standard" (1992), particularly in the shape of **Ss-e**. The heat load increased in **Glazing +** of all directions, especially in the south and in the shapes of **Ss-i** and **Ss-e**.

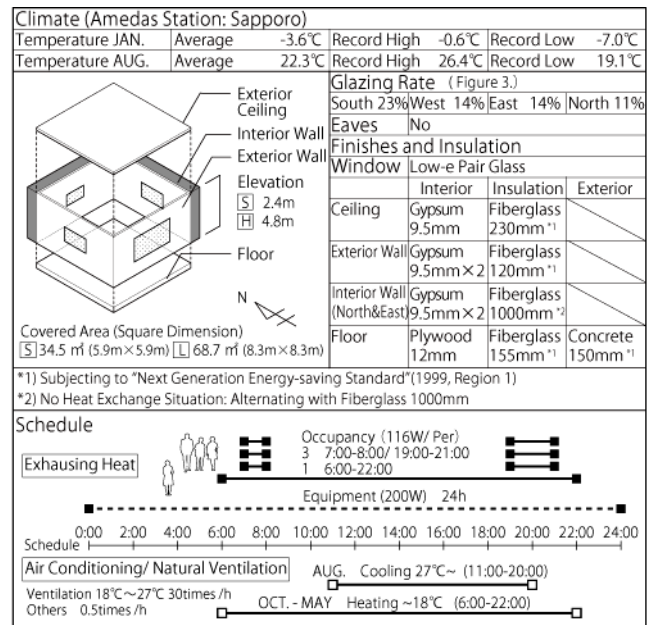


Figure5. Baseline

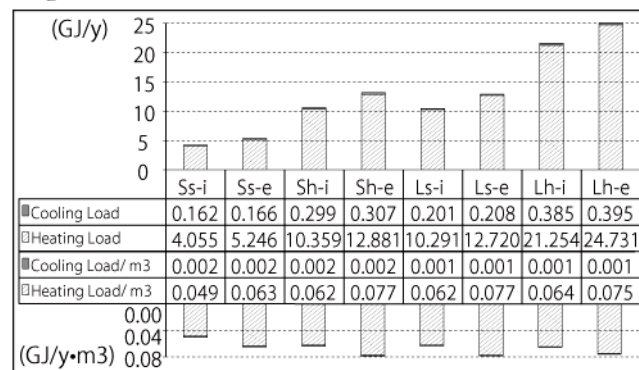


Figure6. Heat Load of Basic Shape Prototypes

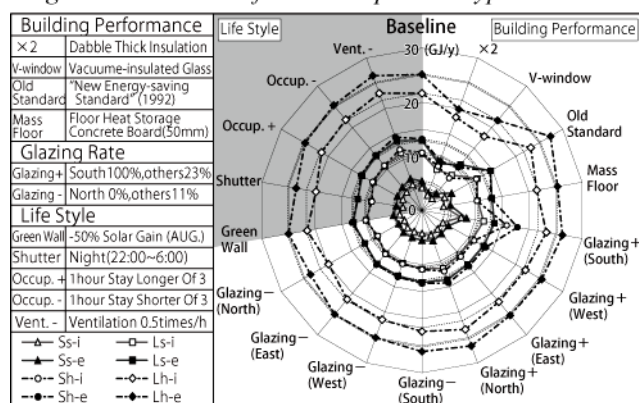


Figure 7. Building performance alternate

When we focus on the life style, the heat load decreased in **Green Wall**, + **Shutter** and + **Occupants**: **Green Wall** means greenery sunshade in August, + **Shutter** means a nighttime shutter and + **Occupants** means three people staying in the place one hour longer. The decrease effect was great in + **Shutter** and in the shapes of **Ss-i** and **Sh-i**. In - **Occupants** and **Vent.** -, the heat load increased: - **Occupants** means three people staying in the place one hour shorter and **Vent.** - means in airtight situation. Small dimension has small energy consumption and the improvement of heat insulation performance, decreasing glazing rate without a south façade and a nighttime shutter restrain energy consumption.

#### 4. Thermal Environment on Main Room Models

The different combination of the setting leads to different inference as shown in this chapter. According to the result of Chapter 3, 48 alternate combinations of building performance and living style are set (Figure 8). The air conditioning load was examined in 48 combination of 8 basic space prototypes.

First, we focus on the difference of the heat gain and loss according to the glazing rate and set + aiming at + **Glazing Rate** with full opening in the south and - aiming at - **Glazing Rate** with no openings in the north. Besides, we set several kinds of thickness of insulation: **O** obeying the New Energy-saving Standard, **P** of the same as the baseline obeying the Next Generation Energy-saving Standard, and that of **×2** is double **P**. That is because the standard of insulation performance varies according to the times. Furthermore, we set additional alternates: **V** means **V-window**, **nS** means + **Shutter**, **V & nS** means **V-window** and + **Shutter**, and **mF** means **Mass Floor**.

Second, we examined the difference of the heat load with the baseline systematically by focusing on the dimension as well as the contrastive characteristics of the spatial shape, such as + **Glazing Rate** or - **Glazing Rate** and **int.** or **ext.** (Figure 9, Figure 10). When we focus on the difference by the insulation performance in every dimension, the heat load decreased in **P** and **×2**, although there were combinations of settings that increased the load, with the insulation thickness of **O** in - **Glazing Rate**. On the other hand, in + **Glazing Rate**, there were combinations that increased the load, though there were many combinations decreasing the load with the insulation thickness of **×2**. Furthermore, in any **Glazing Rate**, when we focus on the difference of **int.** or **ext.**, the heat load of **int.** was lower than that of **ext.**

Furthermore, the heat load of **Ss** was considerably smaller than that of **Lh** with all alternates, when we focus on the difference by the dimension. Besides, the band of the load of **Ss** was approximately half that of **Lh**. In contrast, comparing **Sh** and **Ls**, they have almost the same airspace, particularly in - **Glazing Rate**, the band of the load of **Sh** was approximately twice bigger than that of **Ls**. The heat load increased and decreased according to the airspace. However, the increase and decrease in the heat load changed complicatedly even if they have the same airspace, when the area and the height are different like **Sh** and **Ls**. The bands of the



heat load increased to 1.7-2.5 times depending on the insulation performance by changing only height such as to **Sh** from **Ss**. On the other hand, only enlarging the area like **Ls** from **Ss**, the growth rate of the minimum heat load was at the same level as the change to **Sh**, but the growth rate of the maximum was smaller than **Sh**.

Focusing on the relationship between the dimension and the combination of the settings, effective combinations reducing the heat load were more numerous in a larger airspace. Effective combinations on decreasing the heat load are different even in the same airspace. The tendency was remarkable in **+ Glazing Rate**. We examined the effective combination for the heat load reduction in the shapes of **Ls** and **Sh** in **+ Glazing Rate**, in detail. In the shape of **Ls**, the heat load increased in **+** with the insulation performance **P**, **+** and **O- nS** with the insulation performance **O**. In the shape of **Sh**, there were many combinations increasing the heat load than those of **Ls**. The combinations that increased the heat load were in **“+ with int.”** and **“+ and O- nS with ext.”**, even if the insulation performance is **×2**, except for these combinations, the heat load decreased and **O- mF- V& nS** in **+ Glazing Rate** was the most effective combination by the setting of all shapes including **- Glazing Rate**.

## 5. Conclusions

The present study has demonstrated the thermal environment characteristics of main room models of contemporary houses in Hokkaido. The present result suggested the possibility to make an intimate relationship between indoor and outdoor spaces by using large windows in houses in cold climate areas. Not only insulation but also including spatial dimension and glazing rate affects thermal environment. The load changes according to the size of each area, and the small dimension has small energy consumption. By enlarging only the area size or height, effective combinations for load reduction as well as the range of the load changed the results in complex ways. Though the load increases by increasing only glazing rate, increasing glazing rate with insulation reinforcement and additional thermal mass floor is more effective in reducing energy consumption than decreasing glazing rate.

Few studies have investigated the relationship between form and thermal environment by considering influence on heat load by the combination of shape, insulation performance, and living style, especially in houses in cold climate areas. Therefore, the result of this study will provide new materials about the relationship between the environmental characteristic and the morphological characteristic of contemporary houses in Japan. In this study, we focus on the indoor thermal environment on the housing in the cold climate. The relationship between the environmental characteristic and morphological characteristic in the contemporary houses in different climate regions should be clarified. In addition, considering from different viewpoints from this paper such as natural ventilation, is also important. Further work focusing on these issues is necessary and currently being researched [1,2].

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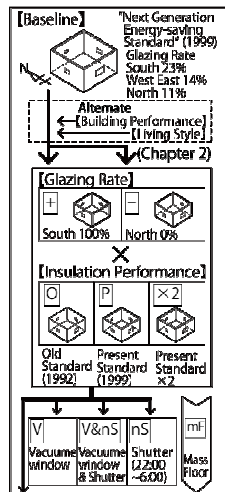


Figure 1 is a complex graph showing the relationship between Load (GJ/y) and various plant parameters (Lh, Sh, Ls, Ss) under different Glaring Rates (South 100% and North 0%). The graph includes data points for combinations of (+) and (-) G/m² V&S, and a legend for Enlarging area and Enlarging height.

The Y-axis represents Load (GJ/y) from 0 to 30. The X-axis represents various plant parameters: Lh (Lh-e, Lh-i), Sh (Sh-e, Sh-i), Ls (Ls-e, Ls-i), Ss (Ss-e, Ss-i), and Base-line. The graph is divided into two main sections: South 100% Glaring Rate and North 0% Glaring Rate.

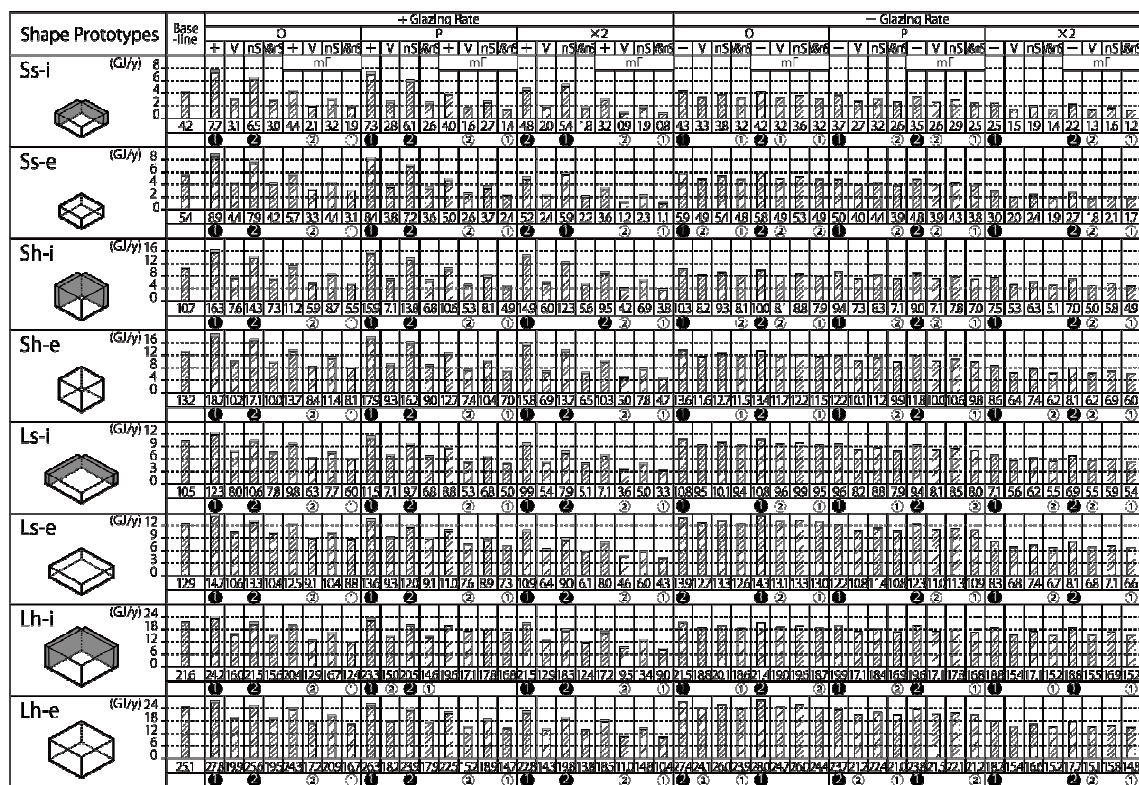
Legend:

- Combination: (+) (filled diamond) and (-) (open diamond) G/m² V&S
- Enlarging area: Shaded area
- Enlarging height: Unshaded area

Key parameters and their values (approximate):

- Lh-e: 25-30 GJ/y
- Lh-i: 15-25 GJ/y
- Sh-e: 15-25 GJ/y
- Sh-i: 10-20 GJ/y
- Ls-e: 10-20 GJ/y
- Ls-i: 5-15 GJ/y
- Ss-e: 5-15 GJ/y
- Ss-i: 5-15 GJ/y
- Base-line: 0-5 GJ/y

**Figure10. Characteristics of thermal environment**



Heating Load(GJ/y)      Cooling Load(GJ/y)

[1] Kisa Fujiwara, Yuko Ono et al. (2014.09). Characteristics of The Thermal Environment of Models of Continuous Spaces of Houses in Tokyo (Part.1), Summaries of Technical Papers of Annual Meeting AIJ

[2] Yuko Ono, Kisa Fujiwara et al. (2014.09). Characteristics of The Thermal Environment of Models of Continuous Spaces of Houses in Tokyo (Part.2) , Summaries of Technical Papers of Annual Meeting AIJ